Seabottom Acoustics Parameters from Reverberation Vertical Coherence in Shallow Water

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(Work supported by ONR, USA and IOA, CAS)

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **01 DEC 2002**	2. REPORT TYPE **N/A**	3. DATES COVERED -

4. TITLE AND SUBTITLE **Seabottom Acoustics parameters from Reverberation Vertical Coherence in Shallow Water**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Georgia Institute of Technology, Atlanta, GA 30332, and Institute of Acoustics, Chinese Academy of Science, China**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
Also See: M001452, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**25**	

ABSTRACT

Acoustic reverberation in shallow water involves a two-way sound propagation and boundary scattering process. It must, therefore, contain rich information on seabottom acoustic parameters. Reverberation from one shot offers a continuous spatial sampling of surrounding sound field. Thus, inversion of seabottom acoustic parameters from shallow-water reverberation is very attractive for saving time and cost. Wide band reverberation data have been collected from the first China-US joint ocean acoustics experiment in the Yellow Sea (Yellow Sea '96) and from the Asian Sea International Acoustic Experiment (ASIAEX01) in the East China Sea. Using the R-mode method and introducing a concept of average angular spectrum for sound propagation, Zhou developed a theoretical model for reverberation spatial coherence and average reverberation intensity in shallow water [Zhou, Acta Oceanologia Sinica, **1,** No. 2, 212-218 (1979) and Acta Acustica, **5,** No. 2,86-99 (1980)]. In the current paper, this model is converted back to a more familiar summation of normal-modes. With this model, the sound velocity/attenuation in sediments and bottom scattering strength are derived for low- and mid-frequencies from at-sea experimental data (YS78,YS96 and ASIAEX01), including reverberation vertical coherence and average reverberation intensity.

I. MOTIVATIONS:

1.Engineering application

Optimal array processing requires...

2. Physics

Forward: how Ocean environments effect on RVC

Backward: inversion of seabottom Acoust. Parameters

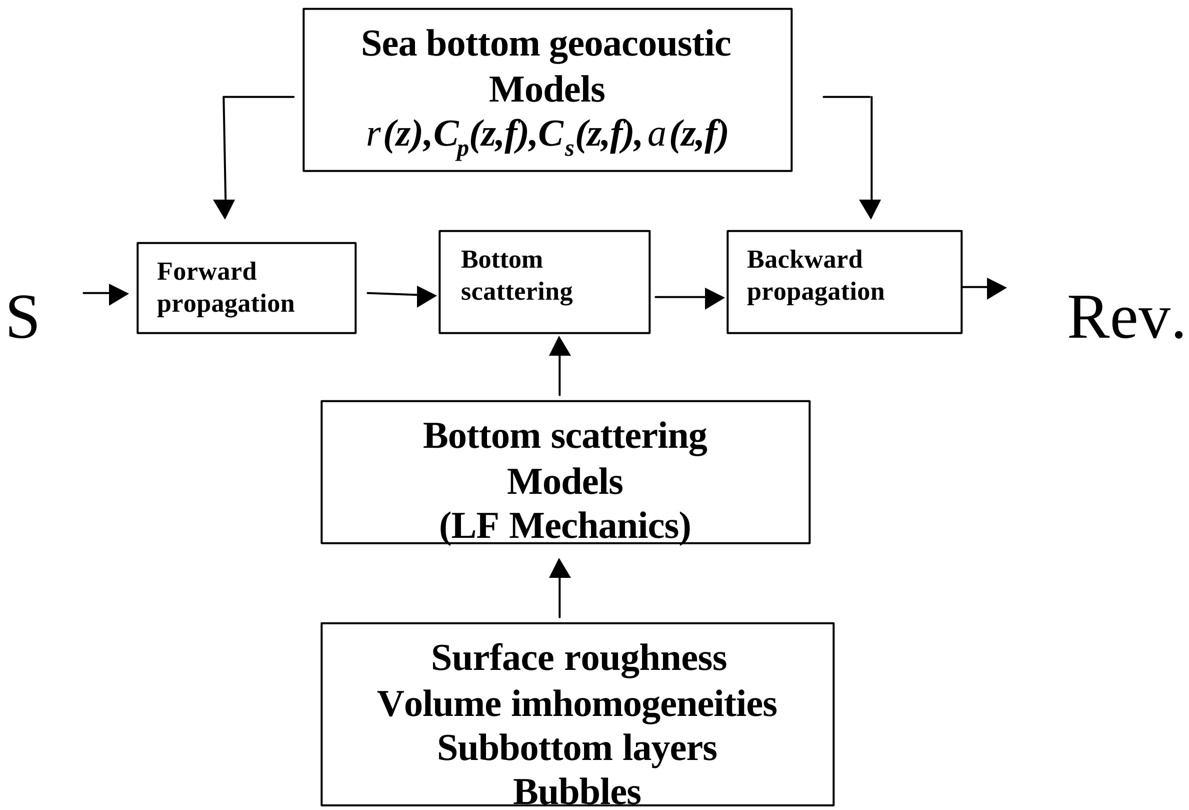
(Rev. derived $S_b(\theta)$ is often mixed with uncertainty of C_2 and $\alpha_{2.}$)

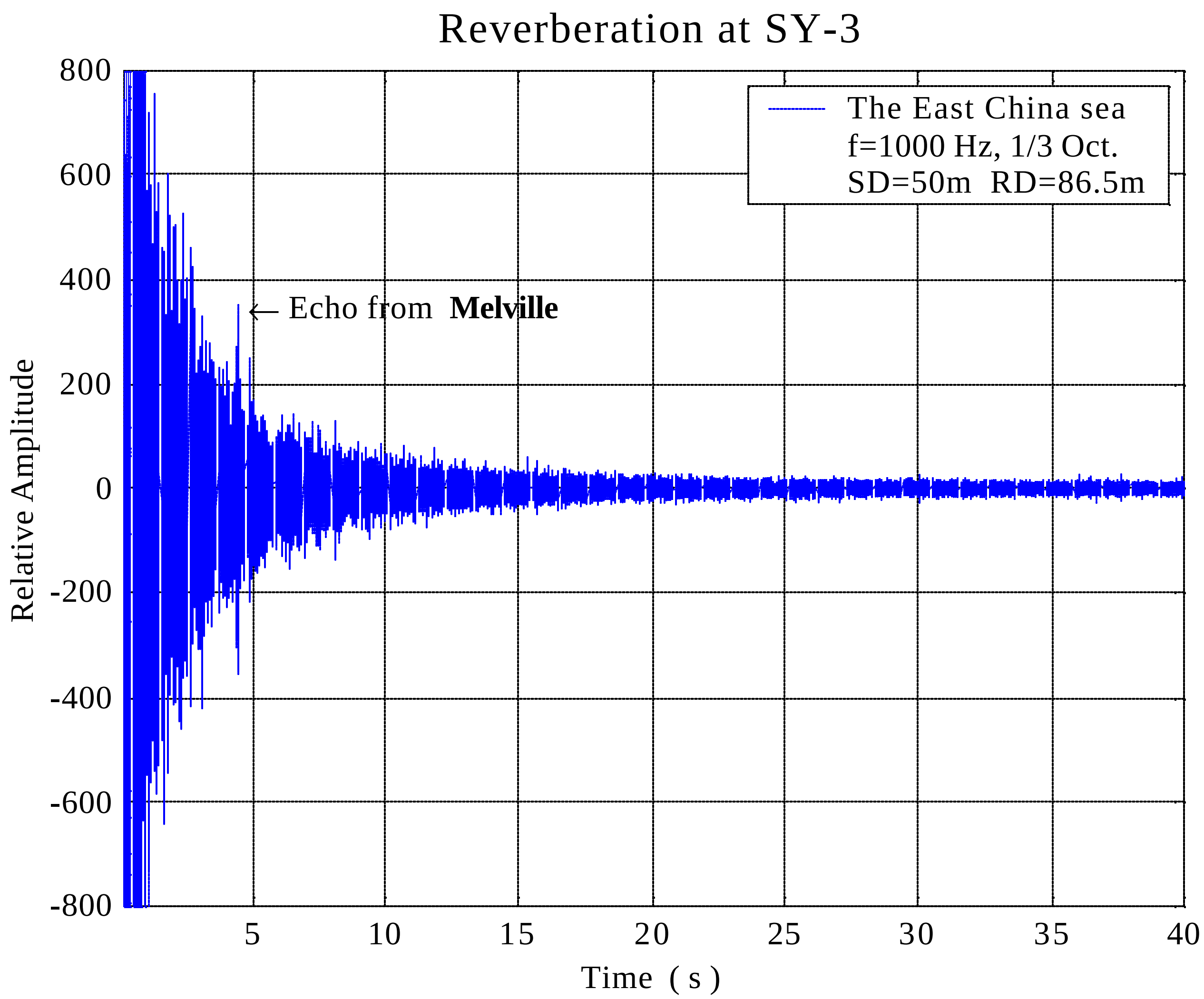
Urick: (1970) $\rightarrow$ HC/VC measurements

Zhou *et al* (1979,1993,1997) $\rightarrow$ Model/data

Popov *et al* (1994)]

Reverberation challenges many basic research topics in shallow water





Reverberation at SY-3
The East China sea
f=1000 Hz, 1/3 Oct.
SD=50m RD=86.5m
← Echo from **Melville**
Relative Amplitude
800
600
400
200
0
-200
-400
-600
-800
5
10
15
20
25
30
35
40
Time (s)

II. THORY

The sound field intensity in shallow water can be expressed as a sum of normal modes:

$$|y\,(r,z;z_0)|^2=\frac{2p}{r}\sum\left\{\frac{|\Phi_n(z_0)|^2|\Phi_n(z)|^2}{k_nN_n^2}e^{-2b_nr}\right.$$

$$\left.+\frac{2p}{r}\sum\sum_{n\neq m}\frac{\Phi_n(z_0)\Phi_m^*\Phi_n(z_0)\Phi_n(z)\Phi_m^*(z)}{k_n^{1/2}k_m^{1/2*}N_nN_m^*}e^{i(k_n-k_m^*)r}\right\} \qquad (1)$$

$$|\Phi_n(z)|^2 = \frac{c_1}{k_n \tan q(z)}$$

$$k_n = k(z)\cos q(z)$$

$$2\int_{x_n}^{h_n}\sqrt{k^2(z)-k_n^2}\,dz + e_{x_n} + e_{hn} = 2np$$

$$\frac{d}{dn}\int_{x_n}^{h_n} f(z,n)dz = \int_{x_n}^{h_n} f_l^{'}(z,n)dz + f(h_n,n)\frac{dh_n}{dn} - f(x_n,n)\frac{dx_n}{dn} \qquad (2)$$

Angular spectrum expression on average intensity of Shallow-water sound propagation (Brekhovskikh,Zhou)

$$I(r,z;z_0) = \frac{4}{r} e^{-ar} \int \frac{e^{2\ln|v(q)|r/s(q)}}{S \times \tan q(z)} dq(z_0) = \frac{2e^{-ar}}{r} \int I_{aps}(q,r,z;z_0) dq(z_0) \quad (3)$$

$$I_{aps}(q,r,z;z_0) = \frac{2e^{-2b_n r}}{S \times \tan q(z)} = \frac{2e^{2\ln|v(q)|r/s(q)}}{S \times \tan q(z)} \quad (4)$$

weighting process in an angular domain for average characteristics in shallow water: Sound propagation, Noise, Reverberation Spatial coherence, etc.

Simple
Intuitive

Angular spectrum expression on average reverberation intensity in shallow water

$$R(r,z;z_0) = \iint \frac{e^{-ar}}{r} I_{aps}(q,r,z_h;z_0) \times AM_b(q,f) \times \frac{e^{-ar}}{r} I_{aps}(f,r,z;z_h)\,dq\,df$$

$$= \iint \frac{e^{-ar}}{r} \frac{2e^{2\ln|v(q)|r/s(q)}}{S \times \tan q(z_h)} \times AM_b(q,f) \times \frac{2e^{2\ln|v(f)|r/s(f)}}{S \times \tan f(z)} \frac{e^{-ar}}{r}\,dq(z_0)\,df(z_h) \qquad (5)$$

$$dq(z_0) = \frac{2p}{S_n k(z_0) \sin q_n(z_0)}\,dn \qquad (6)$$

$\rightarrow$a summation of normal-modes by

Zhang and Jin (1984,1987)

D.D. Ellis (1994).

VERTICAL COHERENCE

For sound propagation by Smith (1976) and Zhou(1979):

$$r_v(\Delta z, r, z; z_0) = \frac{\iint I_{aps}(q, r, z; z_0) \, | S(w) |^2 \, e^{-jk\Delta z \sin(q)} dq dw}{\iint I_{aps}(q, r, z; z_0) \, | S(w) |^2 \, dq dw} \quad (7)$$

For reverberation (Zhou,1979):

$$r_{Rv}(\Delta z, r, z; z_0) = \frac{\int \frac{e^{-2 b_n r}}{S \times \tan q(z)} M[q(z_h)][\cos[k(z)\Delta z \sin(q(z))] dq(z_h)}{\int \frac{e^{-2 b_n r}}{S \times \tan q(z)} M[q(z_h)] dq(z_h)}$$

$$r_{Rv}(\Delta z, r, z; z_0) =$$

$$\left\{\sum_n \frac{e^{-2b_n r}\cos[k(z)\Delta z \sin q_n(z)]M[q_n(z_h)]}{S_n^2 \times \tan q_n(z) k(z_h) \sin q_n(z_h)}\right\}$$

$$\times \left\{\sum_n \frac{e^{-2b_n r} M[q_n(z_h)]}{S_n^2 \times \tan q_n(z) k(z_h) \sin q_n(z_h)}\right\}^{-1} \qquad (9)$$

$$S_n \approx -\,{}^{2p}\!\big/\!{}_{(dk_n / dn)} \qquad (10)$$

III. MEASUREMENTS

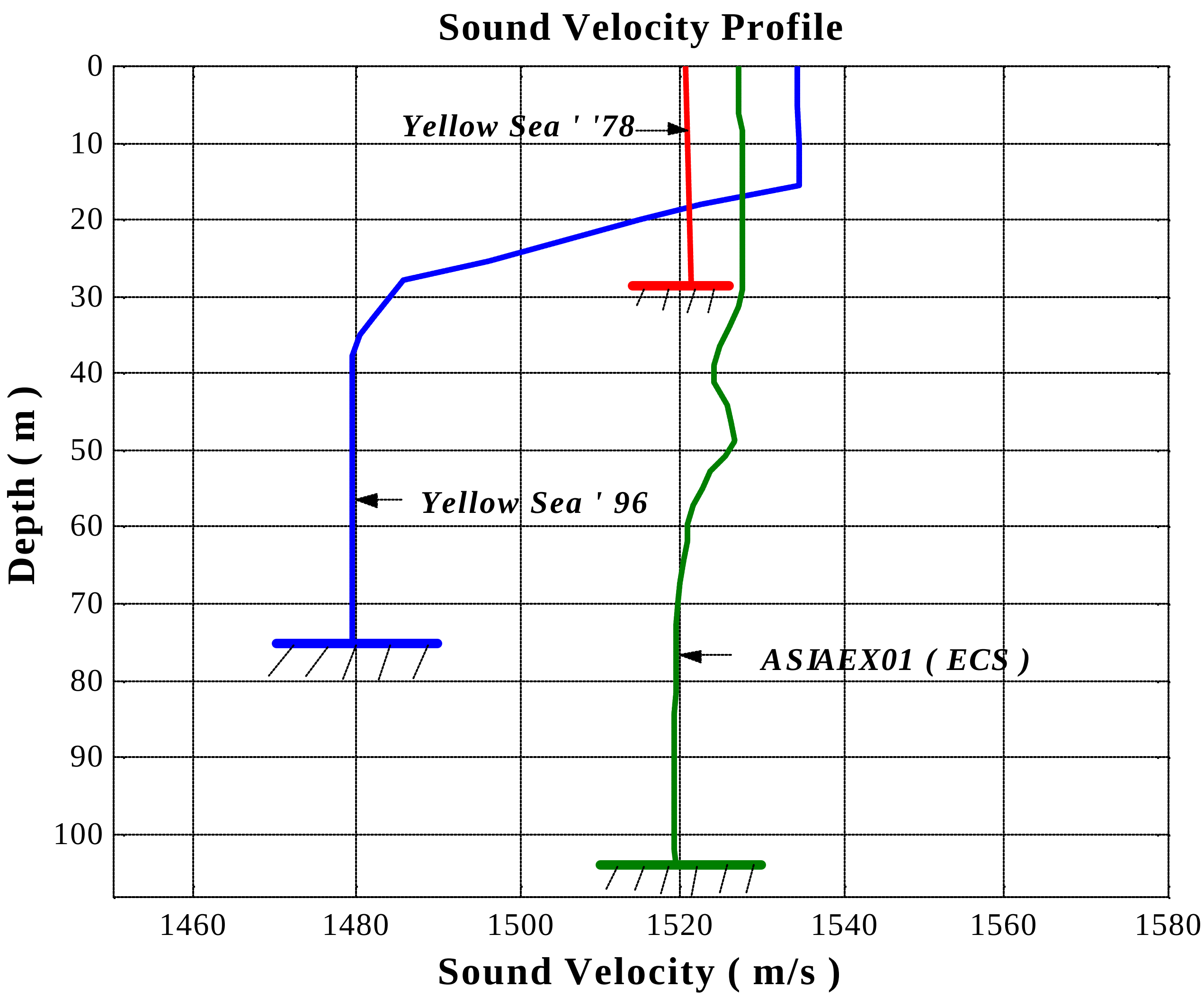
The experiments were conducted at 3 sites in China Seas
by using explosive source with 1 kg gram TNT charges.

Seabed is very flat at YS78/YS96 sites; rather flat at AIAEX01.
The mean grain diameter of sediments:
0.070mm (YS78), 0.0643mm (YS96) and 0.105mm (? ASIAEX01).
Seabed are mainly find sand-silty sand.

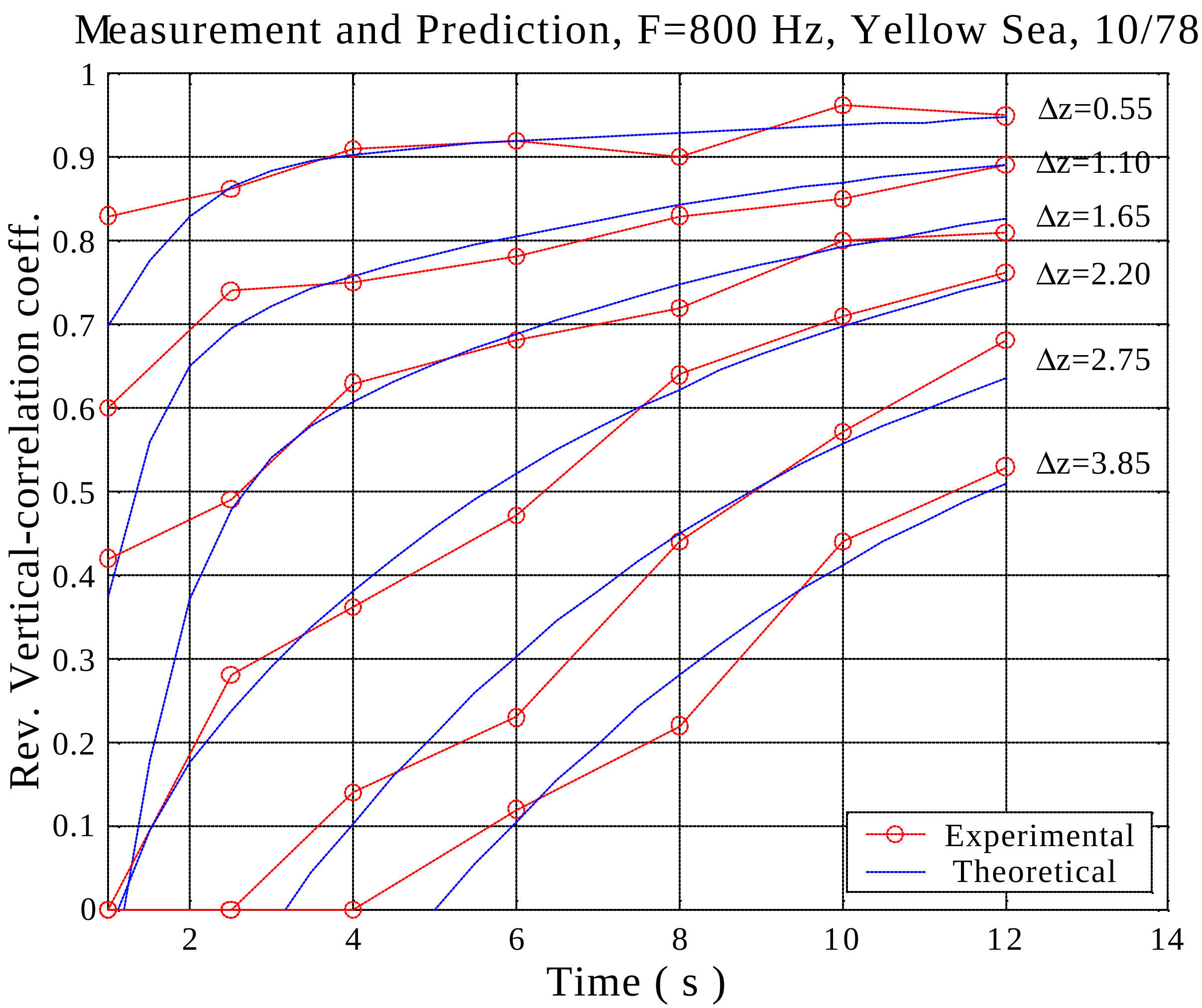
The YS78 data from hydrophones/4-channel analog recorder
The YS96:16 hydrophones/16-channel digital recorder
The ASIAEX01: 32/32

All hydrophone arrays were designed by IOA,
and suspended from ship

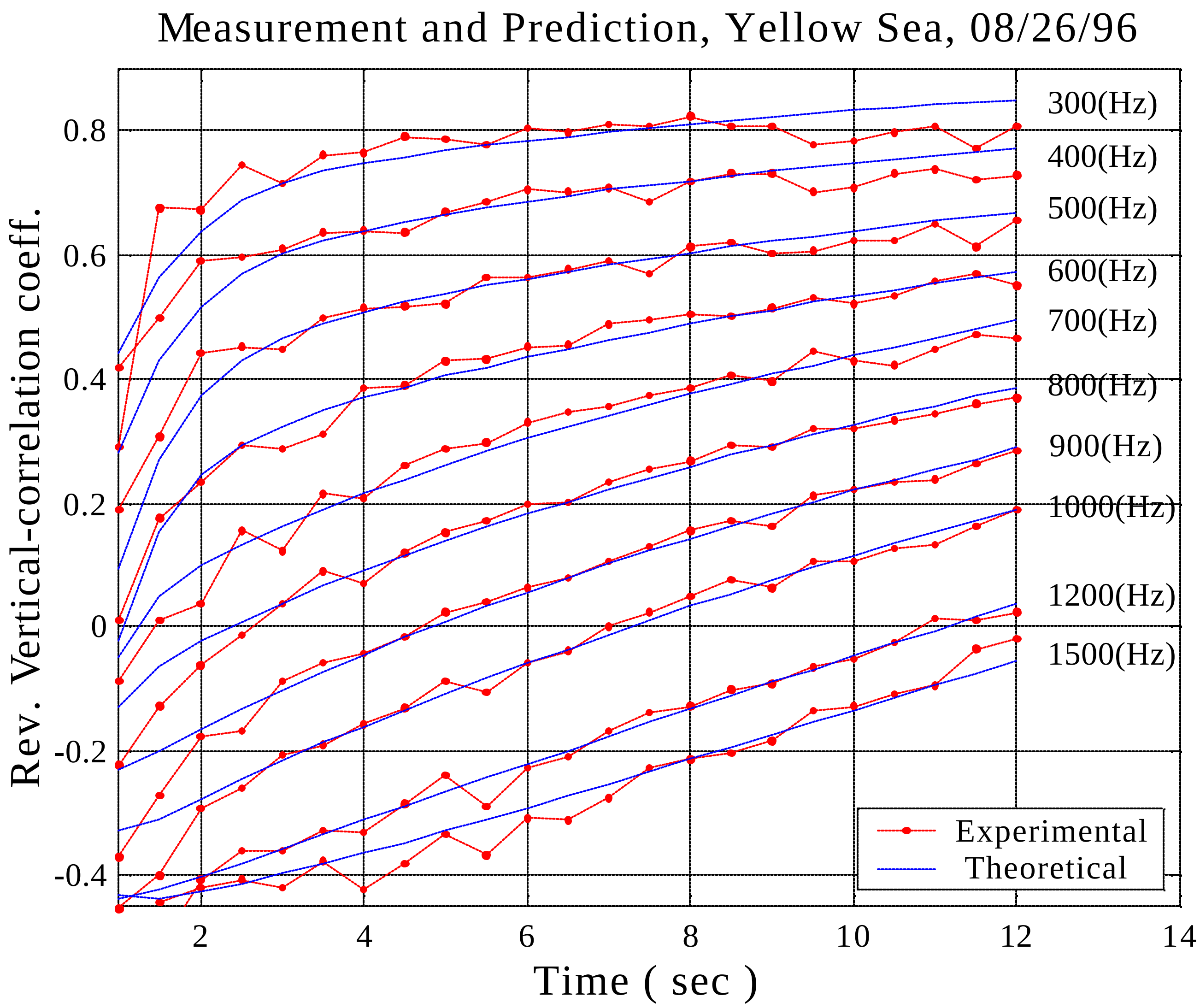
Sound velocity profiles for YS78,YS 96 and ECS ASIAEX01



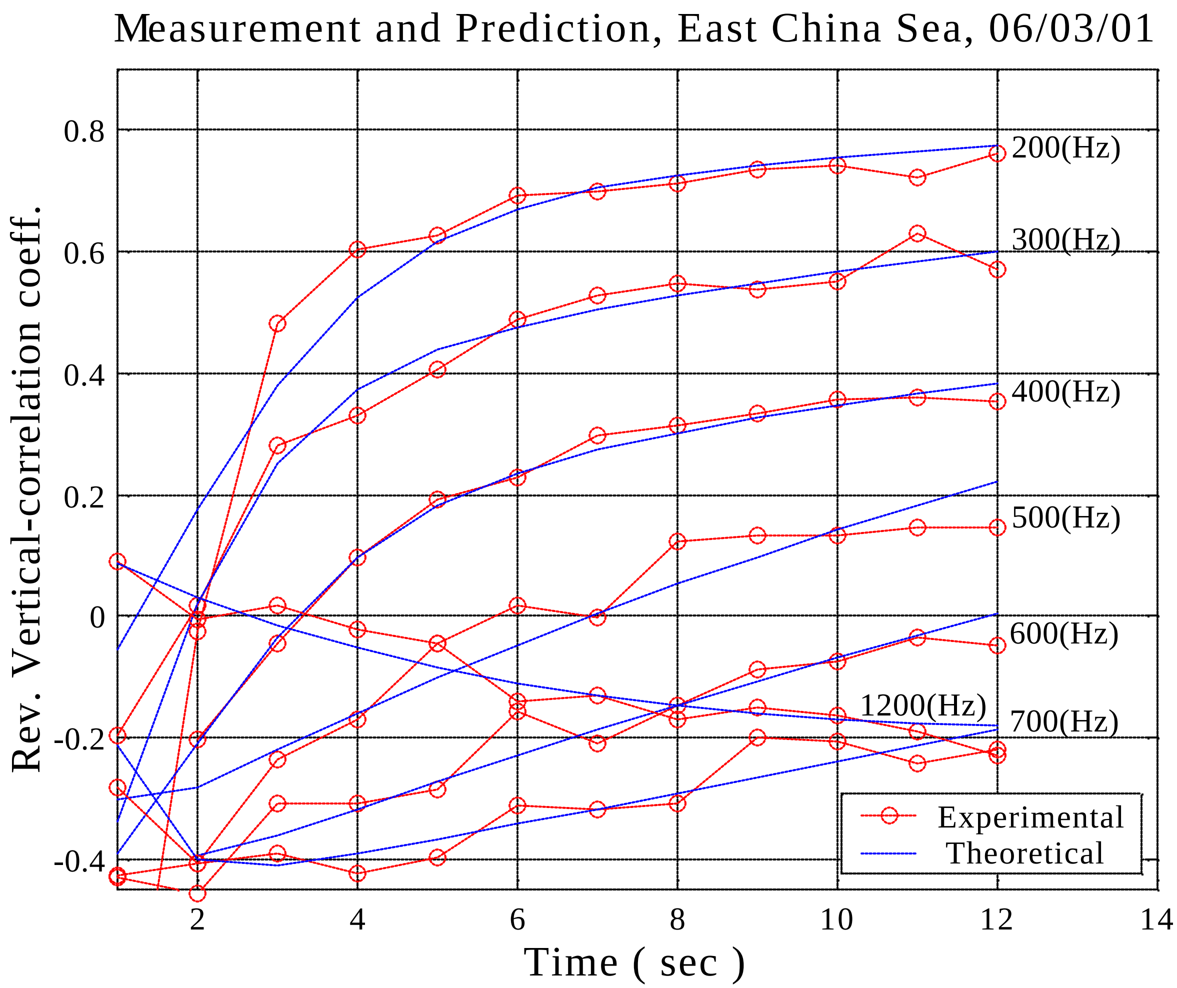
IV. (a) MODEL/DATA COMPARISONS



RV coefficients at 800 Hz as a function time and hydrophone separation and Δz in the Yellow Sea, 1978. Data are average values over 12 explosive signals. Δz=0.55m - 3.85m

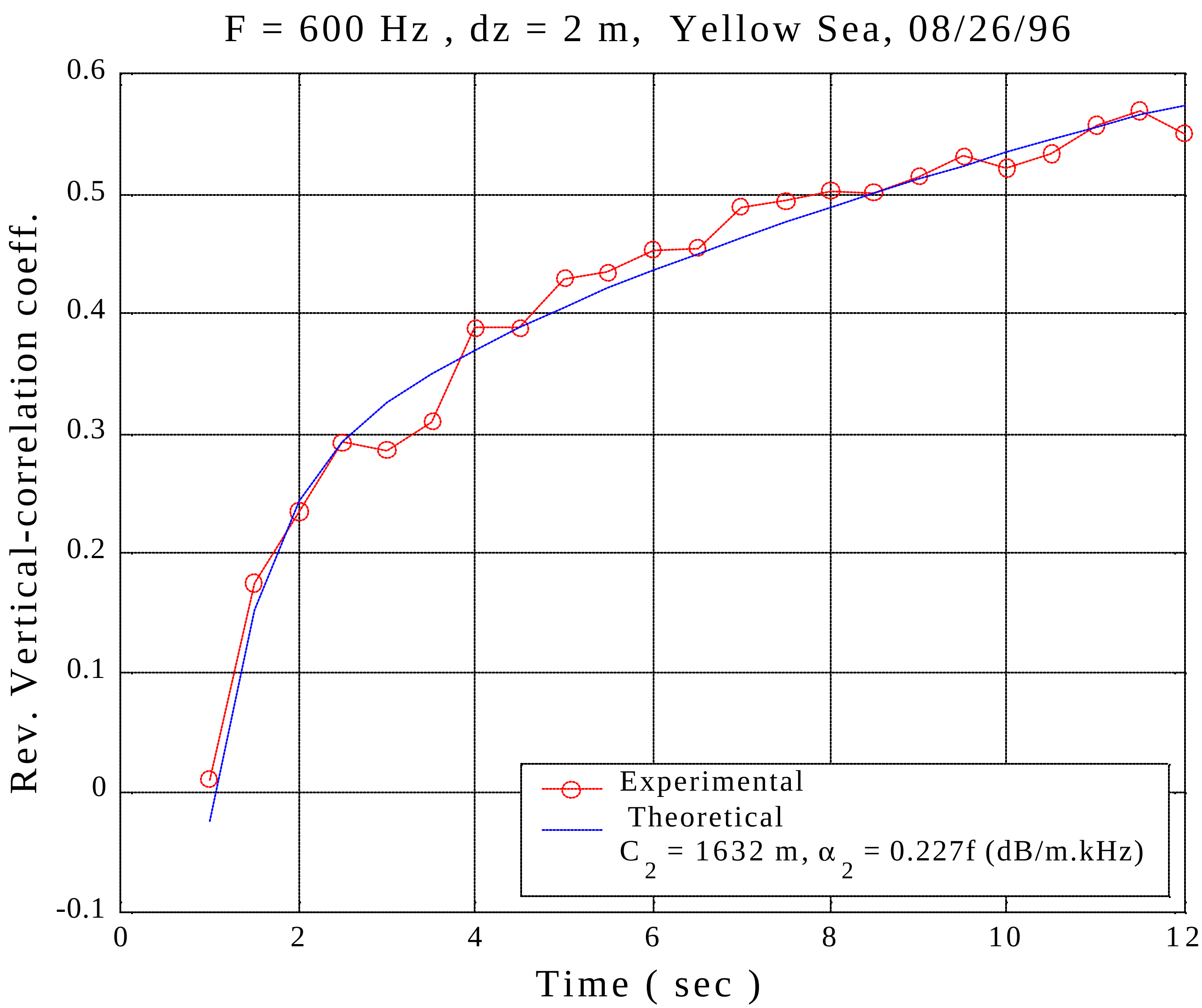


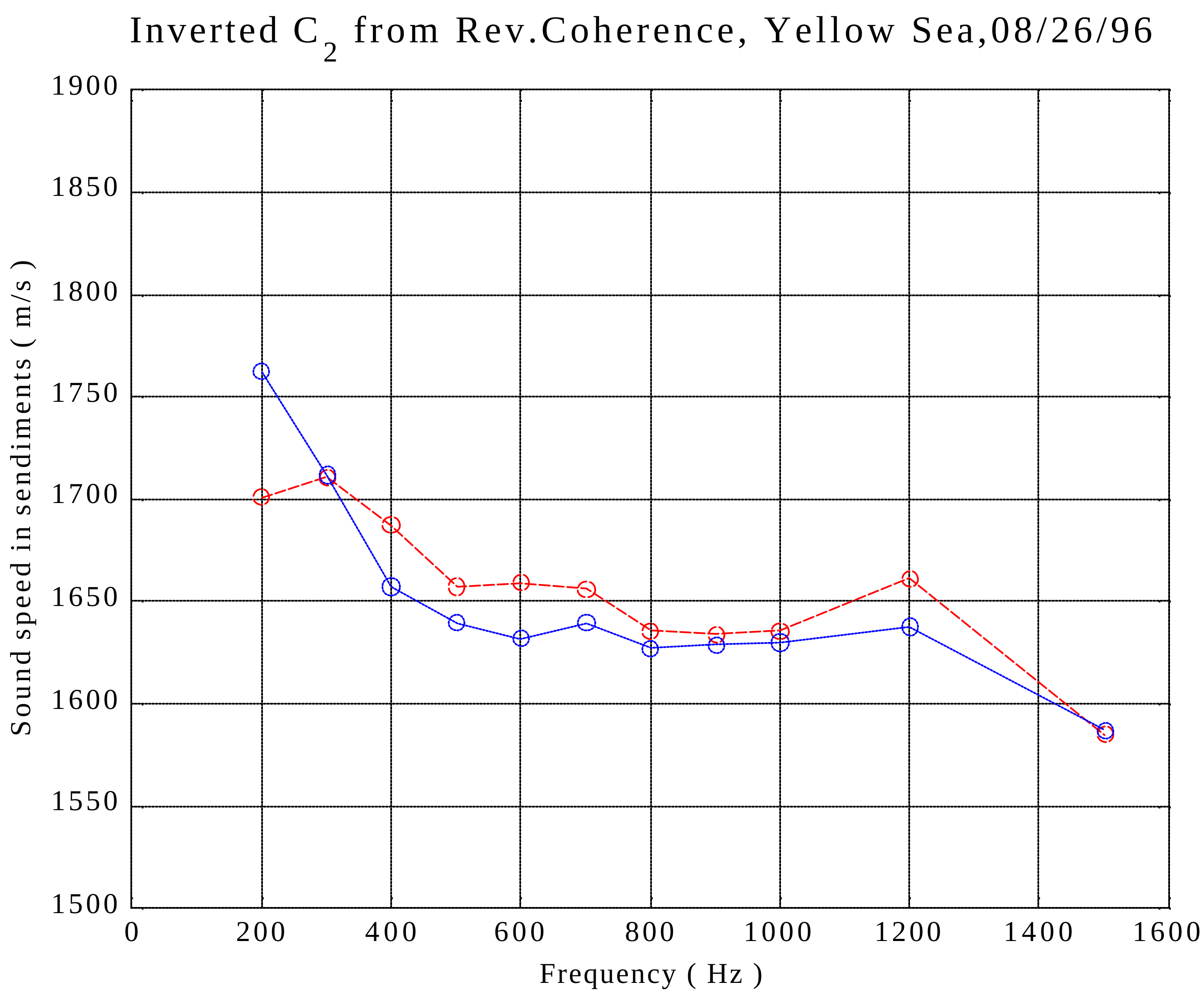
RVC as a function of time and frequency in the Yellow Sea, 1996. Hydrophone separation = 2m. The data are average values of 5 shots and 8 pairs of hydrophones, located at depths from 42m to 66m.



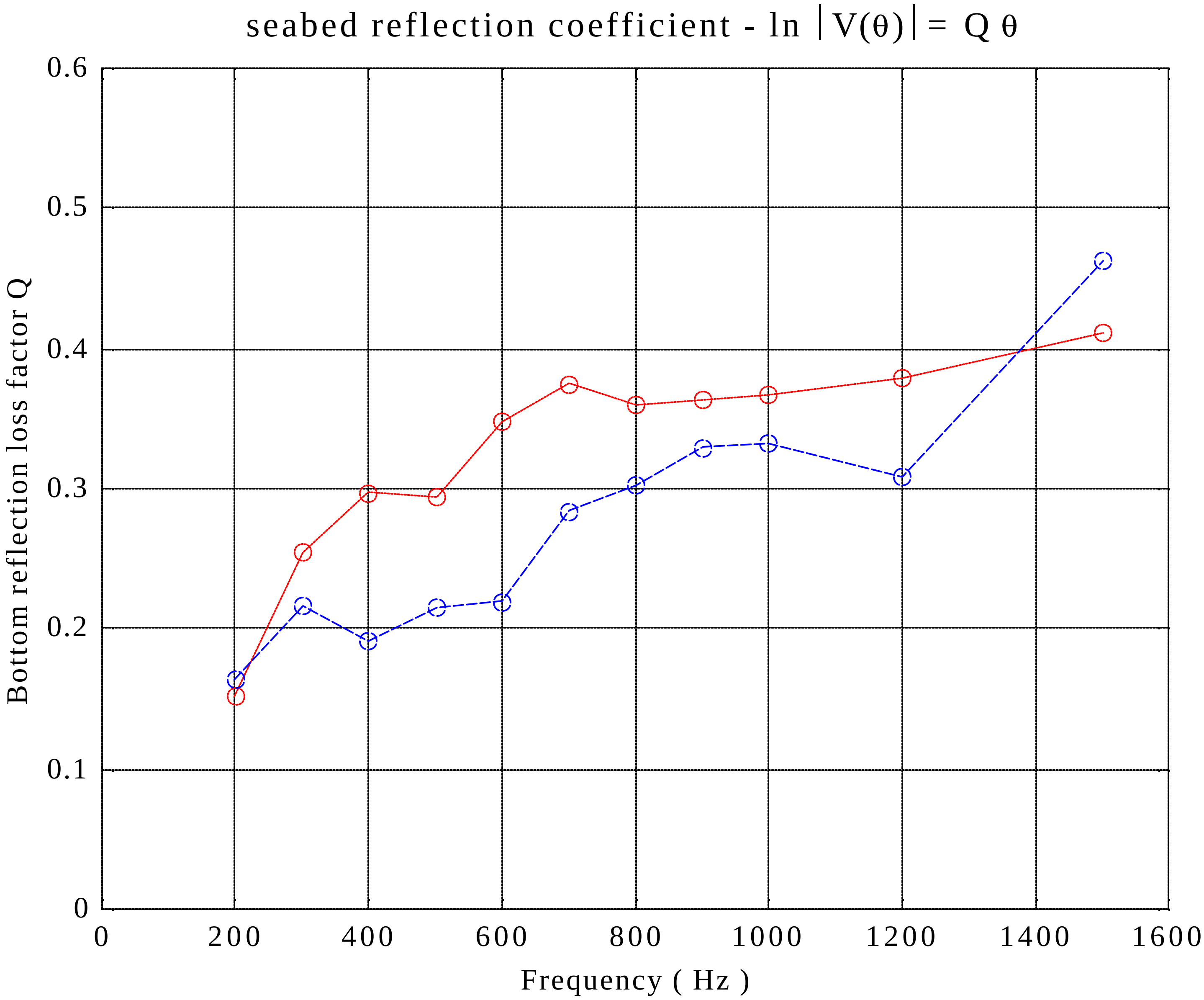
RVC as a function of time and frequency in the East China Sea (ASIAEX01), 2001. Hydroplane separation = 4m.
The data are average values of 3 shots and 8 pairs of hydrophones, located at depths from 56.5m to 90.5m.

IV. (b) INVERSION OF SOUND SPEED AND ATTENUATION FROM YS96 RVC

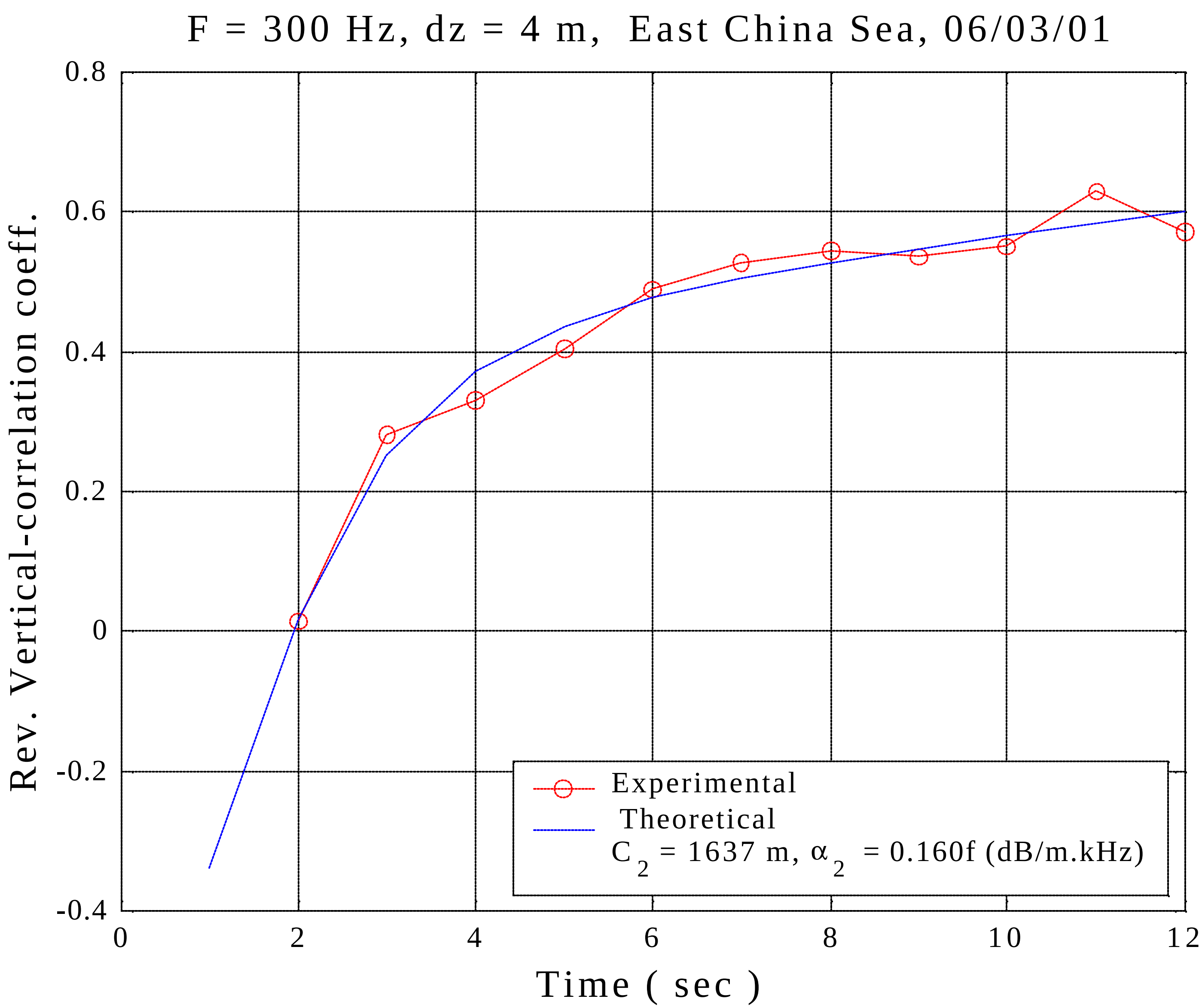


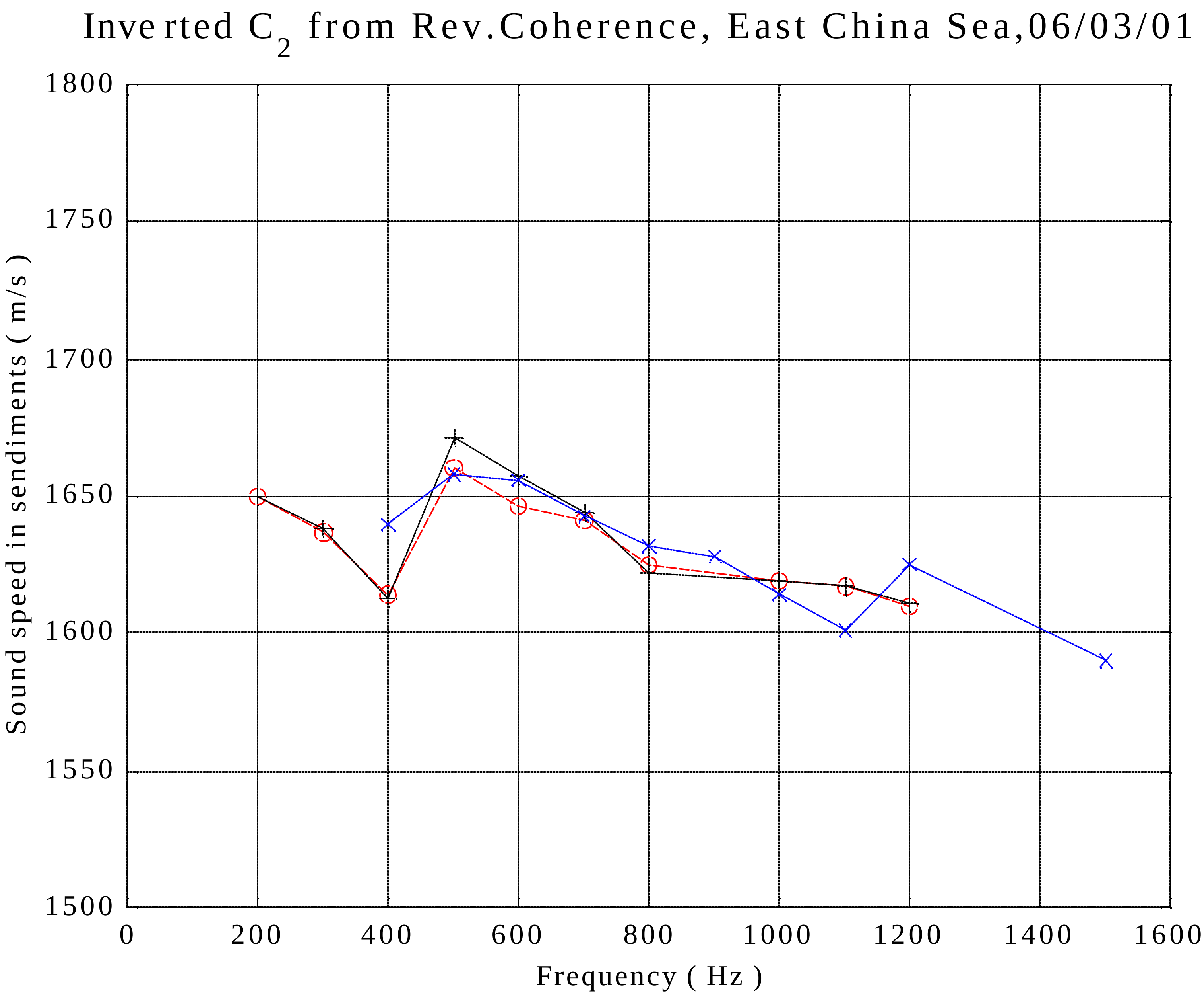


Inverted C_2 from Rev.Coherence, Yellow Sea,08/26/96
1900
1850
1800
1750
1700
1650
1600
1550
1500
Sound speed in sendiments (m/s)
0
200
400
600
800
1000
1200
1400
1600
Frequency (Hz)

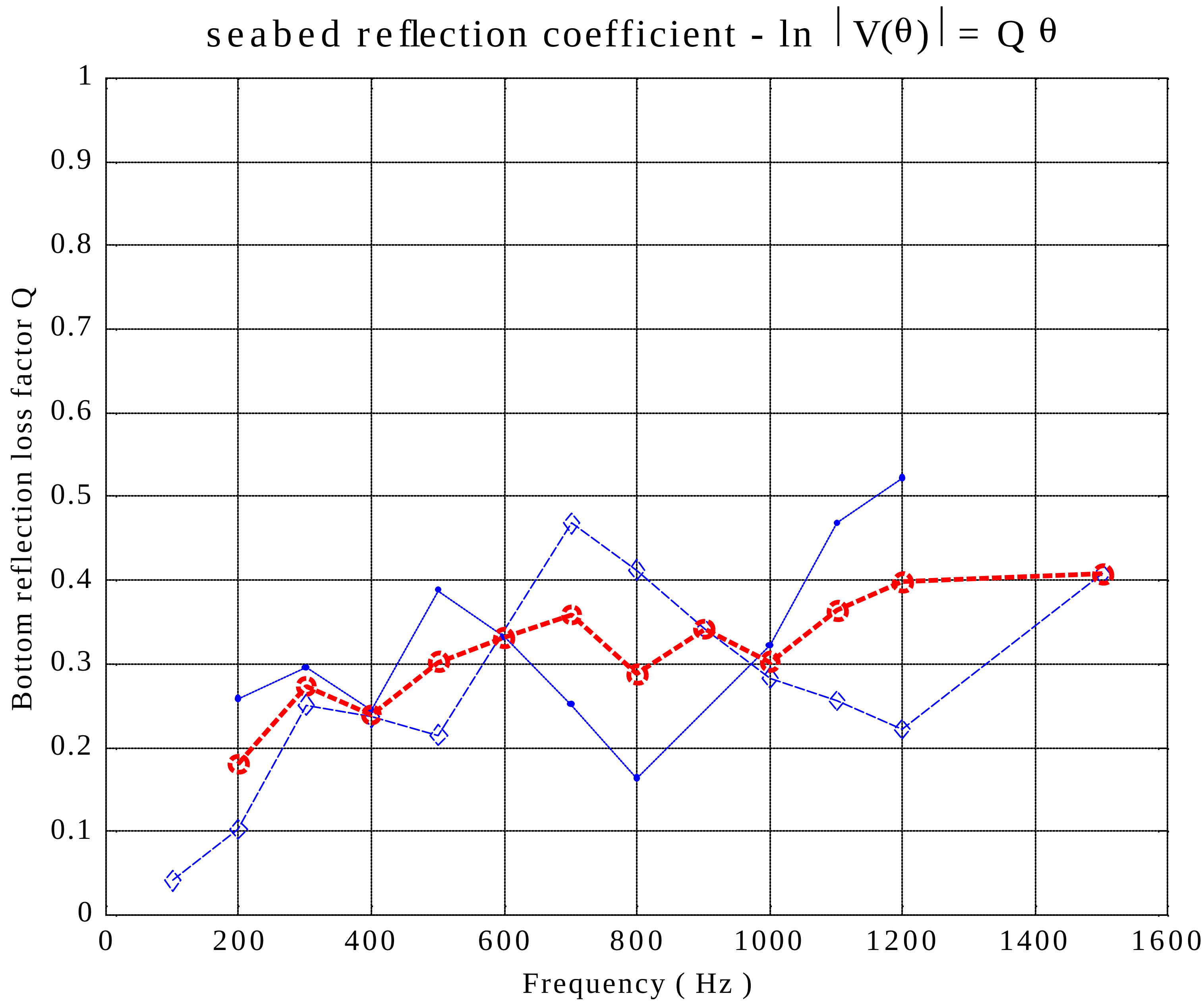

seabed reflection coefficient - ln |V(θ)| = Q θ
Bottom reflection loss factor Q
Frequency (Hz)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
200
400
600
800
1000
1200
1400
1600

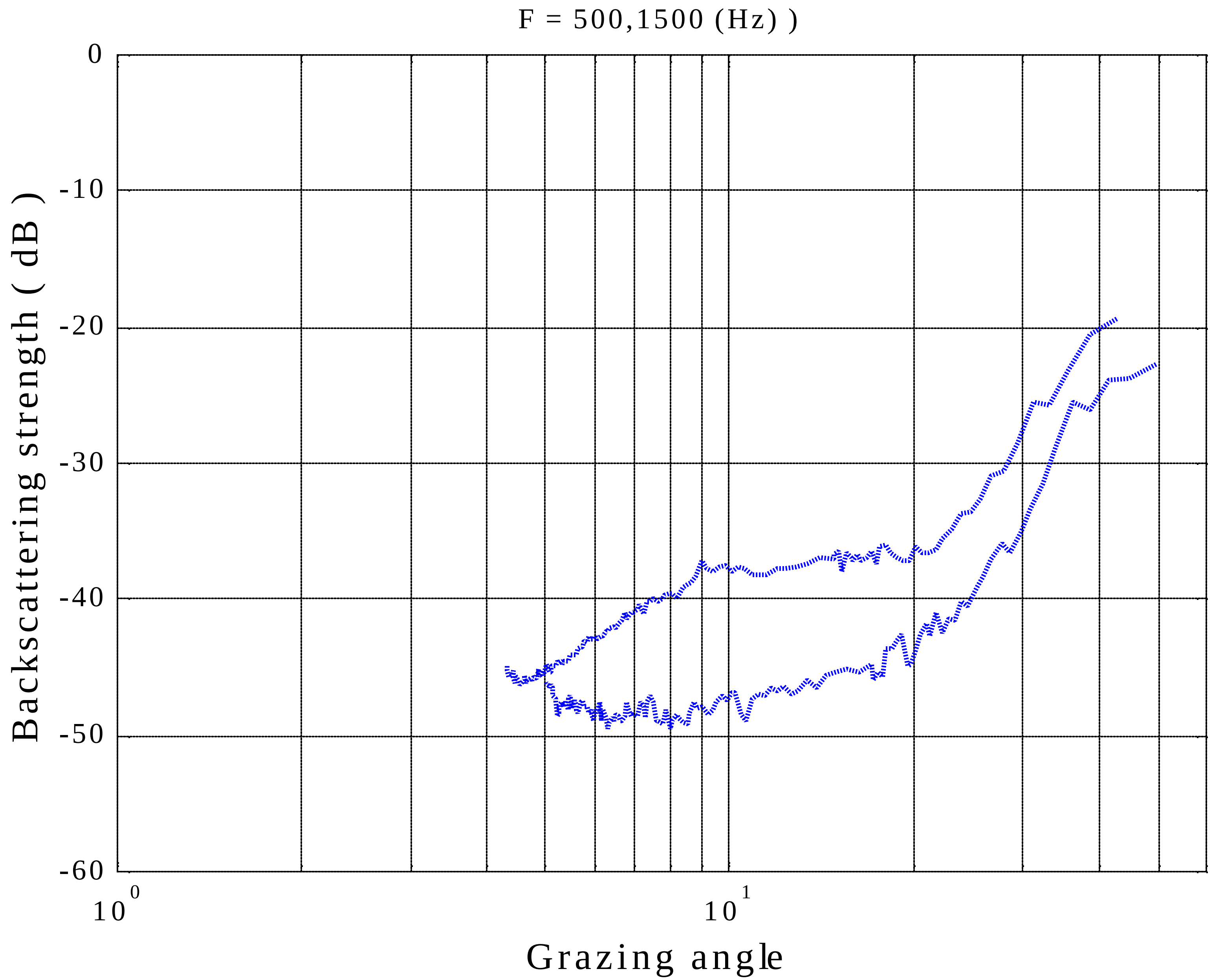
(c) INVERSION OF SOUND SPEED AND ATTENUATION FROM ASIAEX01 RVC





Inverted C_2 from Rev.Coherence, East China Sea,06/03/01
1800
1750
1700
1650
1600
1550
1500
Sound speed in sendiments (m/s)
0
200
400
600
800
1000
1200
1400
1600
Frequency (Hz)


seabed reflection coefficient - ln |V(θ)| = Q θ
Bottom reflection loss factor Q
Frequency (Hz)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
200
400
600
800
1000
1200
1400
1600



F = 500,1500 (Hz))
Backscattering strength (dB)
0
-10
-20
-30
-40
-50
-60
10^0
10^1
Grazing angle

V. SUMMARY AND DISCUSSION

1. The RVC, expressed by the angular spectrum, has been converted back to a more familiar summation of normal-modes.
2. Measured RVC at 3 sites in the China Seas are good agreement with the theoretical model.
3. The sound velocity and attenuation, inverted from RVC, are close to others, inverted from propagation data. Model/data comparisons show that the RVC can be a powerful characteristic for use in fast inversion of seabottom acoustic parameters (and in derivation of bottom scattering strength).
4. Be careful ! Different seabottom scattering models would cause some uncertainty on inversion results of bottom acoustic parameters. Thus, a scattering model with more physical base is desirable for numerical modeling. (under working)
5. For at-sea experiment design and lab data analyses on RVC, one needs carefully to consider the R/N noise ratio and $\Delta z/\lambda$ ratio etc.

Thanks to

IOA colleagues

YS96 & ASIAEX team members

for sharing data and helpful discussions